# High Temperature SHM/NDE

In-situ characterization of the integrity of functional gradient hybrid metal/polymer/ceramic composites

**Sensors and Sensing Network**

Stanford, VT

**Diagnostic Algorithms**

UDRI, VT, UTAM, Stanford

**Modeling**

VT,Stanford

**Integration and Characterization**

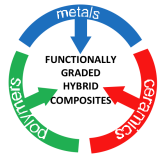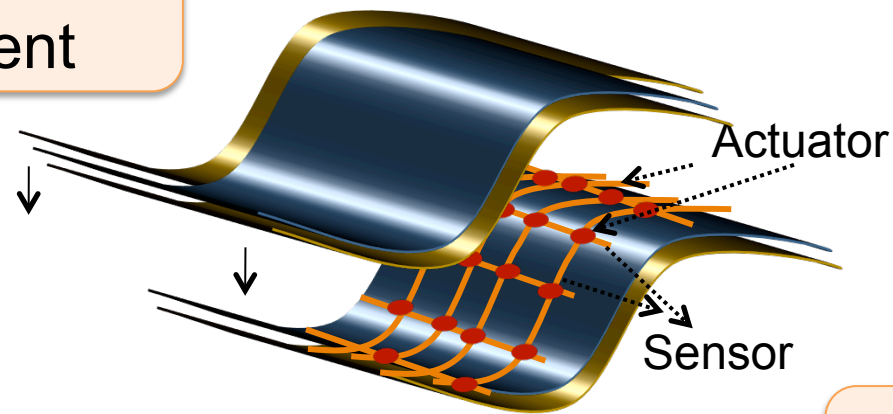UI, Stanford, VT, UDRI, UTAM

*Fu-Kuo Chang*
*Stanford University*

**Monitoring the health state of the hybrid composite materials during manufacturing and in service**
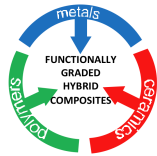
Sensor Network development

Actuator

Sensor

Sensors development

# Sensor Network Development

Development of techniques to integrate sensors into:
(a) hybrid aluminum composites
(b) high T, polymer /ceramic composites

**High Temperature network (e.g. silicon carbide)**

## Network Requirements

- No degradation of the hosting material
- Embedded network
- Control sensors location
- High temperature materials
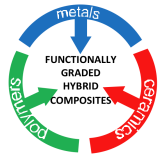- Long-term durability and reliability
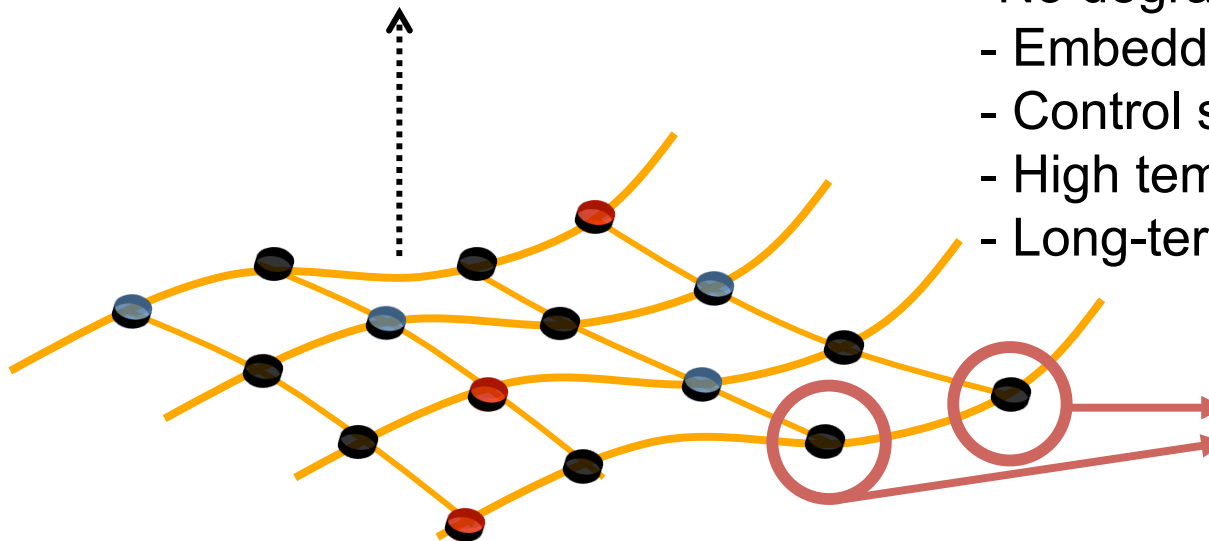
**Integrated Sensors**

# Sensors Development: Piezoelectrics

## STANDARD PZTs

- ## Strain under voltage potential

+ + + +

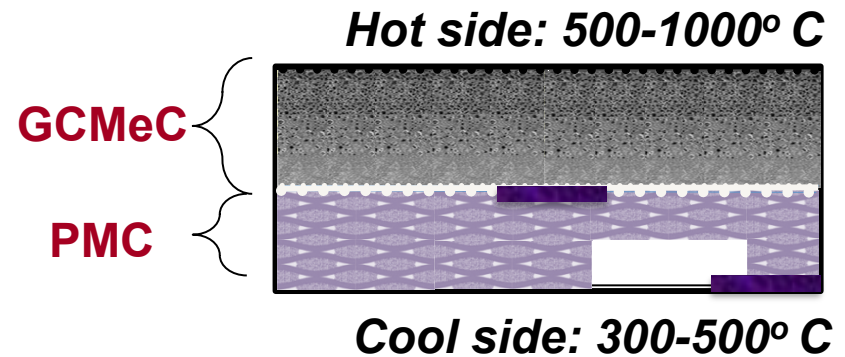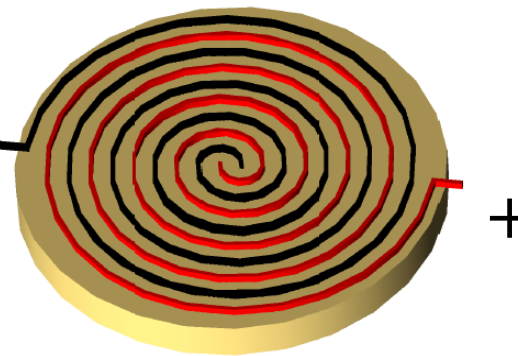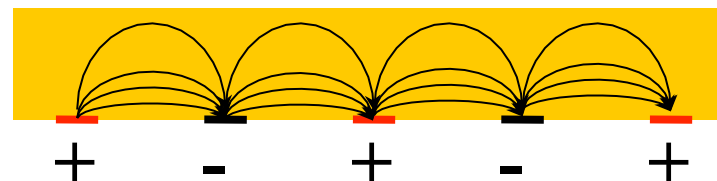- ## Produce potential when strained
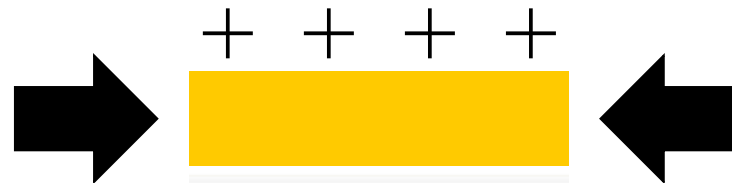
+ + + +
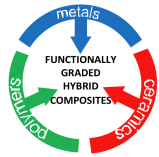
# Sensors Development: Piezoelectrics

Stand-alone sensor placed at the 'cold' surface of the hybrid composite, or potentially at the GCMeC/PMC interface.

*Hot side: 500-1000° C*
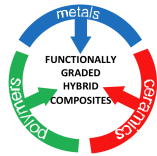
GCMeC

PMC

*Cool side: 300-500° C*
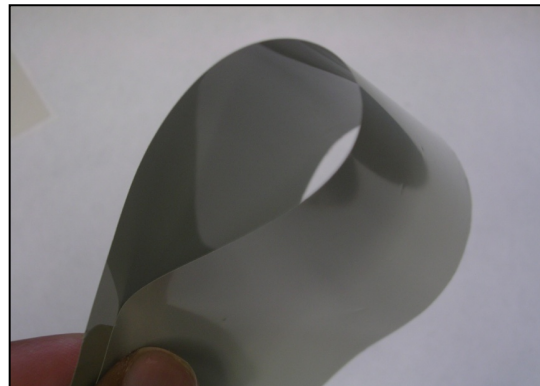
**In Plane Polarization** —

+

**Reduced Layers**

+ − + − +

# *Sensors Development: Piezoelectrics*

- **High Curie Temperature piezoelectric ceramics:**
  - commercially available Bismuth titanate and BST-lead titanate with$T_c$~500-600ºC.
  - Lead titanate-based single crystals

- **Flexible 0-3 piezoelectric composites:**
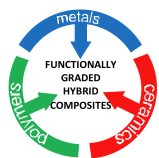  - **Piezoelectric inclusions in polymer matrix**
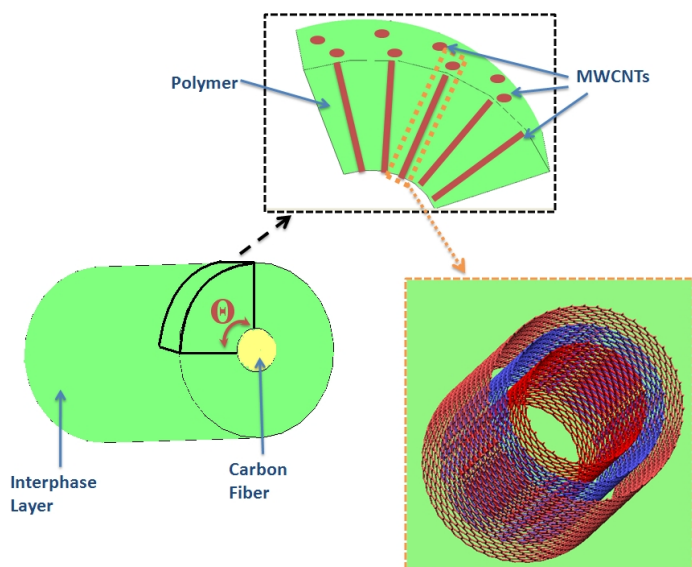


βCN-PI/PZT/SWNT

Texas A&M (SO)

# *Sensors Development: Nanomaterials*

## Conductivity changes

↓

## Strain, damage



Fuzzy fibers

15.0kV 8.5mm x500    100um
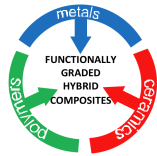
CNTs

E-Beam 5.00 kV | Spot 3 | Mag 2.50 kX | Det SED | FWD 4.946 | Tilt 45.0° | 20 μm

Polymer — MWCNTs

Interphase Layer    Carbon Fiber
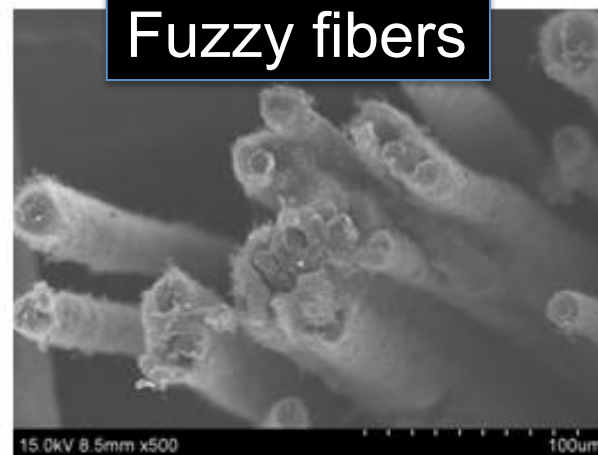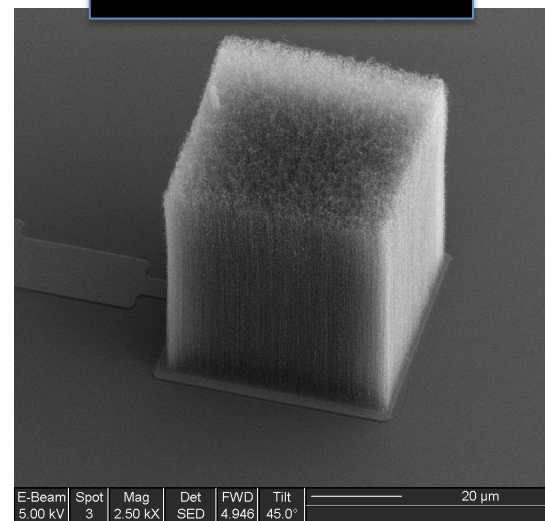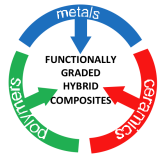
# *Modeling: Temperature effects*

- Temperature effects on damage metrics have been addressed through experimental studies mostly for metals.

- For FGHCs temperature effects on damage metrics will be incorporated  in SHM algorithms based on multi-scale modeling efforts.
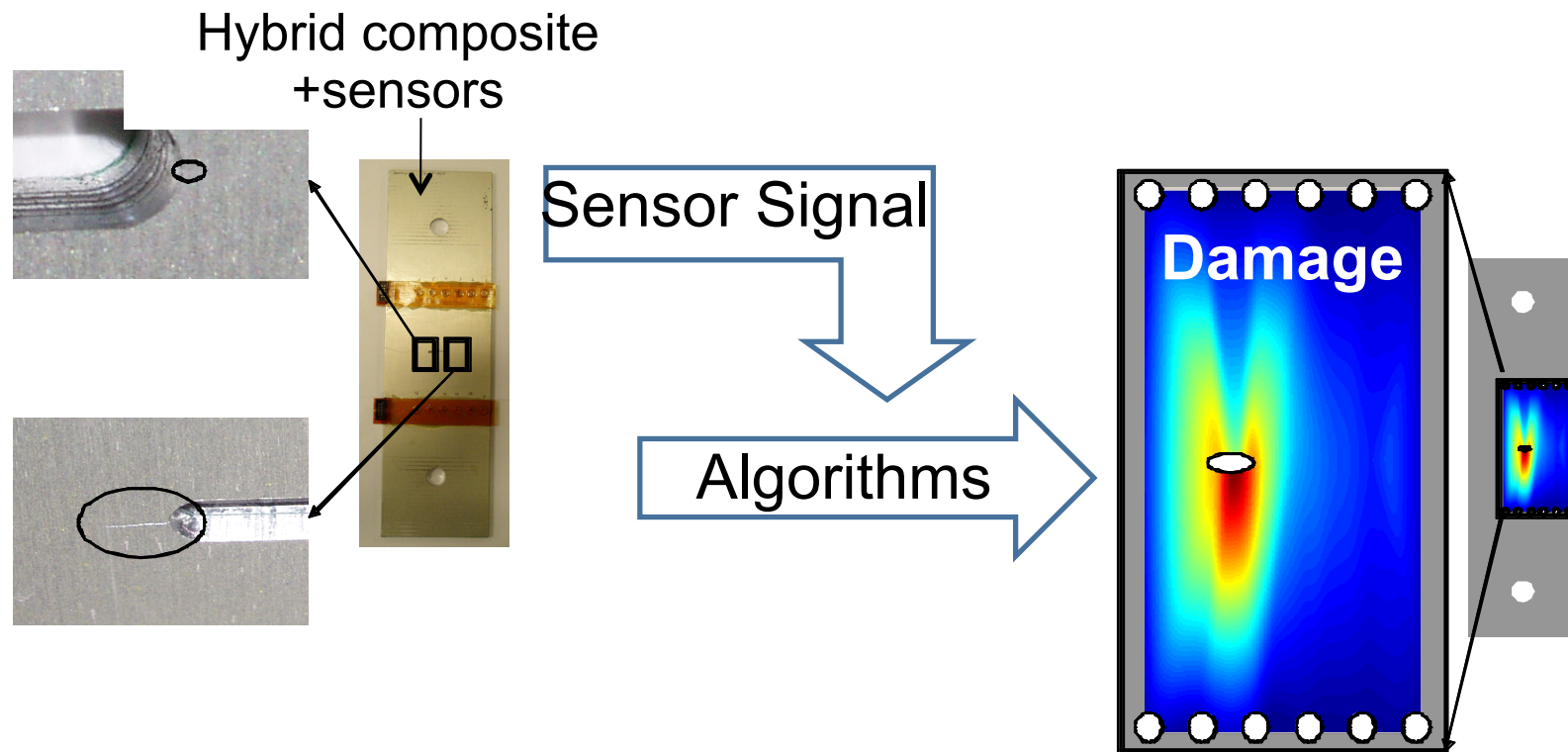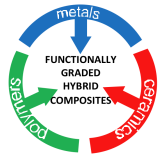
# *Diagnostic Algorithms*

## Develop Techniques to Relate Sensor Signal to Material Properties and Failure



Hybrid composite +sensors

Sensor Signal

Algorithms

Damage

Best Bond

Worse Bond

Nathan Salowitz

# *Diagnostic Algorithms: impact loading*

- Impact determination, location and degree of damage is an important aspect of the proposed hybrid.
- Focus is on impact force identification methods and development of a vibration based approach to determine the damage induced by impact.
- Once the failure modes of the hybrid composites are experimentally determined, correlations between health monitoring signal patterns and the stress redistribution created in the impact zone will be established.

Intermediate velocity test facility
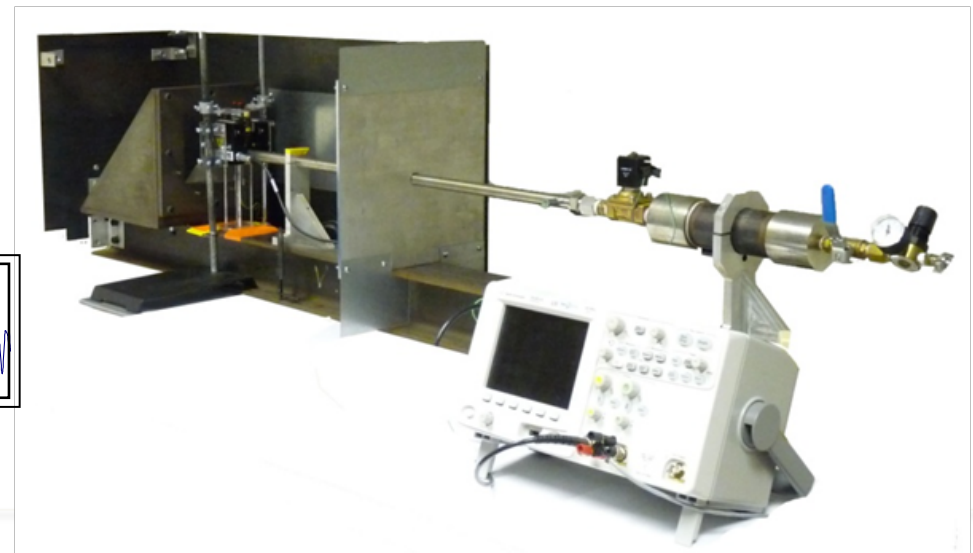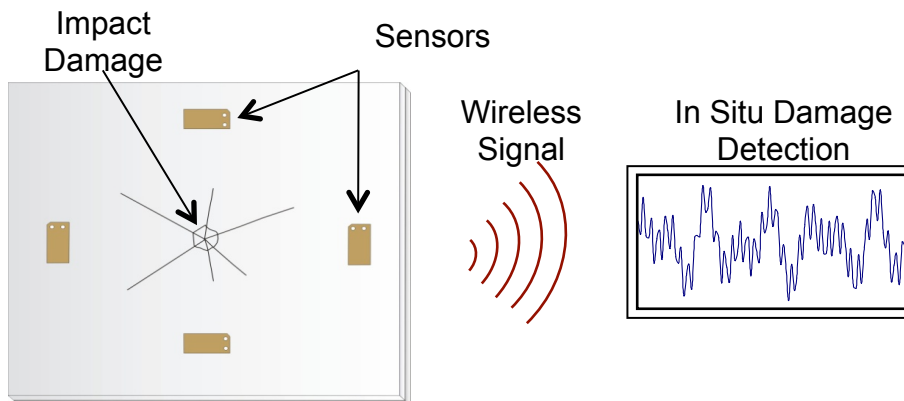


Impact Damage

Sensors

Wireless Signal

In Situ Damage Detection
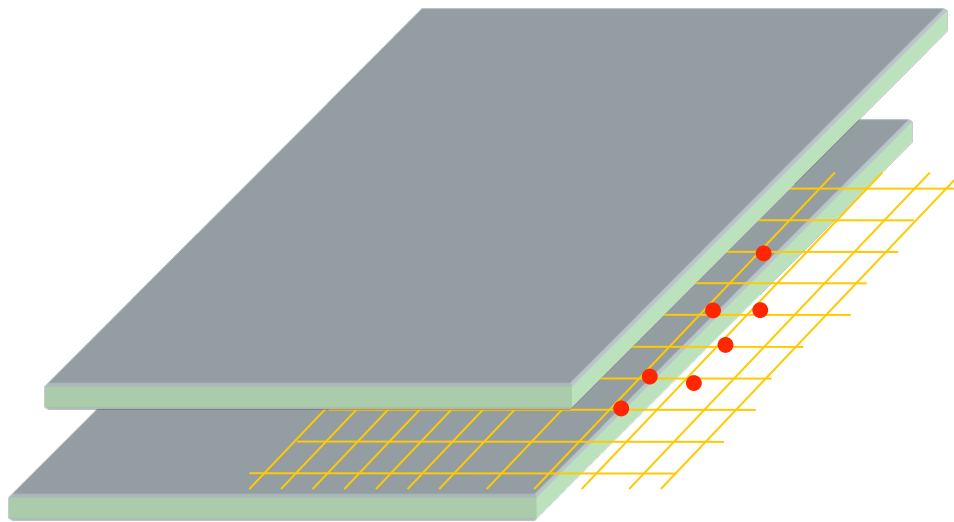
Michigan (NG)
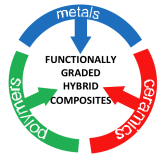
## Testing of Complete SHM/NDE System in Hybrid Composite

Complete system development



- Integration
- Evaluation
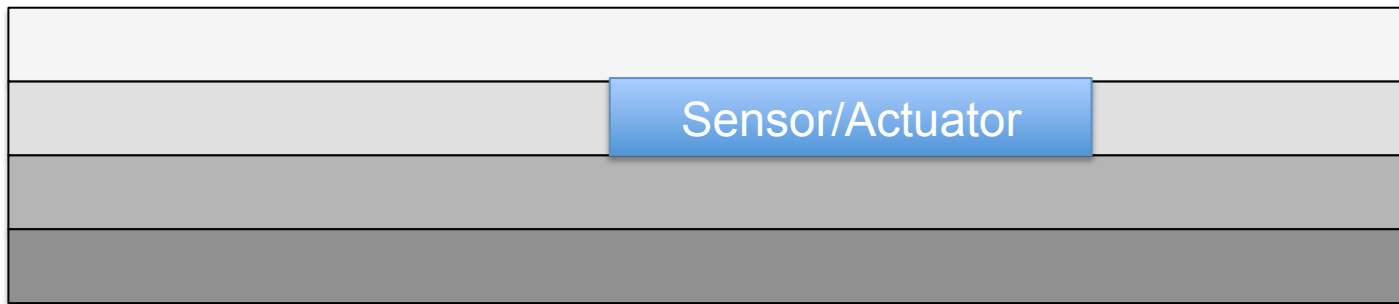- Characterization

- A multi step approach:
- The *first* step is to layer the sensors according to temperature matching Curie temperature with ambient

Cool side: 300-500$^o$ C



Hot side: 500-1000$^o$ C